

# Observation of a linear temperature dependence of the critical current density in a $\text{Ba}_{0.63}\text{K}_{0.37}\text{BiO}_3$ single crystal\*

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For a  $\text{Ba}_{0.63}\text{K}_{0.37}\text{BiO}_3$  single crystal with  $T_c \approx 31$  K,  $H_{c1} \approx 750$  Oe at 5 K, and dimensions  $3 \times 3 \times 1 \text{ mm}^3$ , the temperature and field dependences of magnetic hysteresis loops have been measured within 5-25 K in magnetic fields up to 6 Tesla. The critical current density is  $J_c(0) \approx 1.5 \times 10^5 \text{ A/cm}^2$  at zero field and  $1 \times 10^5 \text{ A/cm}^2$  at 1 kOe at 5 K.  $J_c$  decreases exponentially with increasing field up to 10 kOe. A linear temperature dependence of  $J_c$  is observed below 25 K, which differs from the exponential and the power-law temperature dependences in high- $T_c$  superconductors including the BKBO. The linear temperature dependence can be regarded as an intrinsic effect in superconductors.

It is well known that  $\text{Ba}_{1-x}\text{K}_x\text{BiO}_3$  (BKBO) with  $T_c \approx 30$  K is very suitable for research of high- $T_c$  superconductivity, because it has a simple perovskite structure and characteristics similar to cuprate superconductors. The superconductivity mechanism and the metal-insulator transition for BKBO still remain to be clarified. Up to now, although there has been much research on the superconductivity mechanism for BKBO, only little of the research was carried out on very high quality crystals. In this paper, the critical current and its temperature dependence are investigated by observing magnetic properties of a high quality BKBO single crystal. The results are compared with other work published on BKBO and cuprate data characterized by the power-law and exponential-temperature dependences.

The  $\text{Ba}_{0.63}\text{K}_{0.37}\text{BiO}_3$  single crystal was synthesized by the electro-chemical method reported elsewhere.<sup>1</sup> The size of the crystal with  $T_c \approx 31$  K was  $3 \times 3 \times 1 \text{ mm}^3$ . The potassium concentration was found to be  $x \approx 0.37$  by electron-probe microanalysis. The value  $H_{c1} \approx 750$  Oe was determined at 5 K. The paramagnetic Meissner effect with the crystal was investigated at low fields.<sup>2</sup> The zero-field-cooled (ZFC), field-cooled (FC) susceptibilities and the magnetic hysteresis loops were measured by using a magnetometer of Quantum Design Co. (MPMS7). Before measuring the hysteresis loops, zero setting for the magnetic field was performed to remove any remnant field in the superconducting magnet. A magnetic field of 6 Tesla in the c-direction was applied.

Figure 1 shows the ZFC and FC susceptibilities measured at 4 Oe in the virgin-charged superconducting magnet with the crystal with  $T_c \approx 31$  K. The ZFC absolute value evidently exhibits no temperature dependence up to 24 K indicated by arrow A and decreases rapidly between 24 K and  $T_c$ . In the case of the ZFC susceptibility, the transition width of  $T_c$  is  $\Delta T = 7$  K (defined from  $T_c$  to 24 K). In the Meissner state, the susceptibility is defined as  $-4\pi\chi_m\rho = V/(1-D)$ , where  $\chi_m$ ,  $V$  and  $D$  are the mass susceptibility, volume fraction and demagnetization factor, respectively, while the X-ray density

$\rho \approx 8 \text{ g/cm}^3$ . If  $V$  is assumed to be unity and independent of the field orientation,  $D \approx 0.68$  is calculated from the ZFC susceptibility. If an ellipsoid of revolution is used to approximate the crystal shape with the dimensions mentioned above, then  $D \approx 0.65$ . This agrees fairly with that calculated from the ZFC susceptibility. This agreement indicates that the crystal is fully superconducting, nearly single and homogeneous.

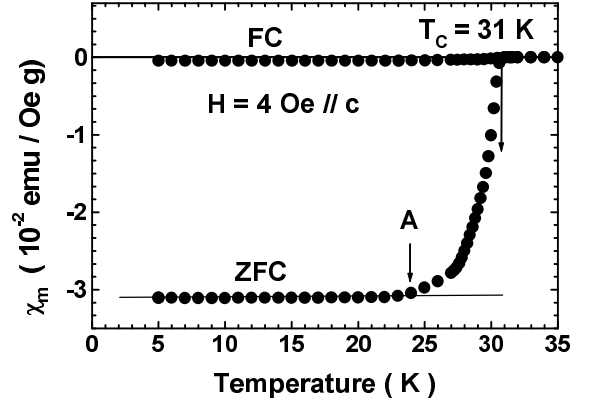


FIG. 1. The temperature dependence of FC and ZFC magnetic susceptibilities.

Figure 2 (a) and (b) show temperature dependences of a half of the magnetic hysteresis loops measured up to 6 Tesla in the 5 - 25 K range; here data are shown only up to 1 Tesla beyond which all functions are very nearly constant. The loops are typical of those observed in high  $T_c$  superconductors. The field and temperature dependences of  $J_c$  are shown in Figs. 2 (c) and (d).  $J_c$  at 5 K at zero field and 1 kOe were evaluated as  $1.5 \times 10^5 \text{ A/cm}^2$  and  $1 \times 10^5 \text{ A/cm}^2$ , respectively, by using the Bean criti-

cal state model<sup>3</sup> applicable to bulk;  $J_c = \frac{10\Delta M}{a - \frac{a^2}{3b}}$  in *CGS* units, where  $a$ ,  $b$  and  $\Delta M$  are the grain dimensions of a bulk crystal and the magnetic moment corrected by the demagnetization factor, respectively. The magnetic field dependence of  $J_c$  decreases exponentially with increasing field up to 10 *kOe*. The temperature dependence of  $J_c$ , as shown in Fig. 2 (d), is linear below  $\sim 25$  K indicated as arrow A in Fig. 1. This indicates that the superconducting condensed state below  $T_c$  has a linear temperature dependence for  $J_c$ . The linear dependence differs from the published results which follow a power-law<sup>4,5</sup> for the BKBO and an exponential dependence<sup>6</sup> for a Hg system. The cause of the difference is that the absolute values of ZFC susceptibilities at low temperatures in these papers are not constant but decrease with increasing temperature<sup>4,6</sup>; *i.e.*, this indicates that the non-linearity (or power law) may be attributed to a pinning effect due to impurities in the crystals. In addition to the above crystal, the linearity for another high quality crystal was observed by the same experimental method.

Finally, we suggest that the linear temperature dependence of  $J_c$  is an intrinsic effect in superconductors.

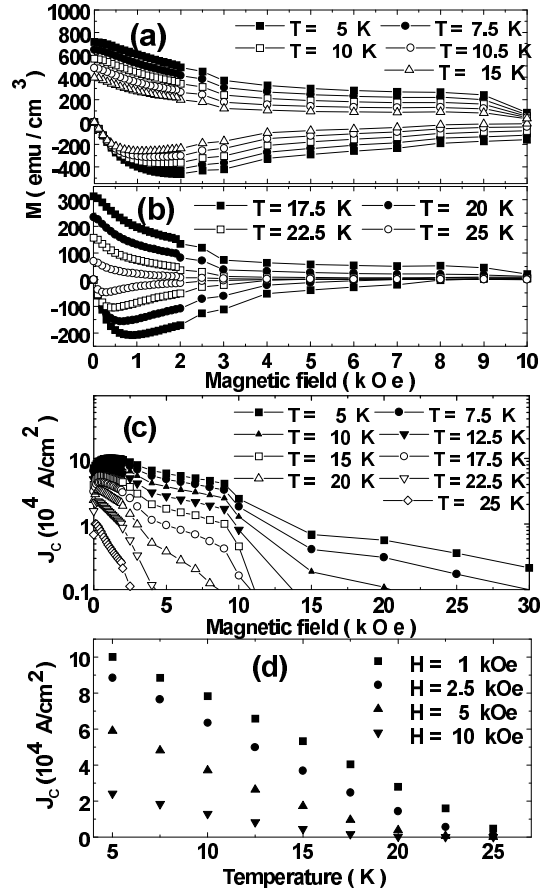


FIG. 2. (a) and (b) the temperature dependence of a half of magnetic hysteresis loops; (c) the field dependence of  $J_c$ ; (d) the temperature dependence of  $J_c$ .

\* Physica C **341-348**, 729 (2000).

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